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COLOR PERCEPTION:

NORMAL AND SUBNORMAL.

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NORMAL COLOR PERCEPTION.

When the most extended nomenclature for color and the richest human color sense are compared with the almost incalculable numbers of ethereal vibrations that are representative of separate and special color impulses, it will be realized that every human subject has a limited power of receiving and interpreting color impressions.

The vast extent of color power possessed by some nations, the wide range of the so-called Radde's color scale, so much used at the present time for commercial purposes, and the wonderful ability of the world-renowned Chevreul, all sink into insignificance when they are thought of in connection with what might be visible were the human organs of vision better developed and able to function to greater degrees.

The merest difference of number of vibratory movements—a single difference—makes a change in color, and each color change gives a different degree of sensory impulse. It is not the artificial mental division of the solar color spectrum, for example, into the well-known seven integral parts (violet, indigo, blue, green, yellow, orange, red) that should be considered. It is not the unscientific and oftentimes nonsensical anatomical construction of a color-perceiving apparatus into adapted component portions that is obligatory. Coarse specialization of receiving tip, transmitting fibre, and discharging molecule is unnecessary. Supposed peculiarities of physiological action. brought forward in order to explain well-known visual phenomena, are useless. For example, chemical chromatic and achromatic actions (Wundt); differences of excitation of the retinal rods and cones (Lederer); localized vibratory actions in the macular region (Salom); vibration movements of the retinal sheet

(Delbouef); movable color molecules in the cerebral color centres (Krenchel); paired anachromatic and katachromatic cones (Preyer); and the better known three-fibre and triple-molecule theories claimed to be outgrowths of Wünsch's hypothesis (Young-Helmholtz, Maxwell, Raehlmann, and Helmholtz), as well as the most remarkable supposed dissimilative and assimilative powers of paired sensations, said to have found birth in Schopenhauer's theory of color vision (Hering); constituting the most important hypotheses that have been offered—are all fallacious and unscientific. These and their many thoughtlessly accepted modifications are in the main so ridiculous when they are made correlatively to apply to the other special senses, that it seems remarkable, considering the present state of minute research, that they are allowed to remain so frequently unchallenged and unattacked.

The fact is, that every difference of color wave gives a different degree of physical impact, as it were, upon the one and the same receiving tip. Each such tip receives such an impression, and in strict conformance with its individual ability transforms the impress into an equivalent active energy. Each transmitting fibre carries this transformed energy to its anatomical representative in the cerebral cortex, in which situation it is ready to be received and interpreted by a series of complicated sensorial acts.

The most highly specialized receiving, transmitting, and discharging portions of the color apparatus are those that have their peripheral terminations situated in the macular regions of the eyeball, at the internal ending of what is known as the direct axis of vision. These, as well as the other receiving tips or peripheral terminations of the sensory neurones, are bathed or dipped, as it were, to different degrees in a number of photo-chemical substances which during their activity are being both constantly used and renewed. The newly made energies rush centripetally along the transmitting portions of their related neuronic tissues to their connected internal prolongations in the occipital cortex, and thus produce corresponding changes in the cortical structures by which momentary molecular mosaics that are the exact representatives of the component parts of the peripherally placed retinal pictures, are obtained.

Each element of the neuronic system has its individual duty to perform, and each portion of every particular neurone does its specific work; so that, as a finite result, a composite expression of

that part of the external world which is visible is placed in a position for perception and recognition.

As each particular sensory neurone has its relative power, and as the most highly developed ones are situated directly in the visual axis, color perception is found to be the best along the line of fixation; red, for example, being the farthest seen, followed by yellow, blue, and green. Moreover, as might be expected, each sensory neurone accomplishes its work with a certain degree of celerity: for instance, yellow is said to be the most quickly seen, followed by blue, red, and green.

From this central area of highest grade of perception of color differences and amount of color saturation, a more extensive area in which the less and less difficult of color changes are successively lost, extends in all directions. This field of color vision, as it is called, extends normally to its greatest breadth down and out. The order of the field widths, as seen clinically for a few of the colors that are the most commonly employed, are green, red, blue, yellow, and white.

As with the individual sensory neurones, so with the various composite series. There is the greatest difference in the color-perception value of different individuals. Visual apparatuses are just as unlike as are any of the other physical structures. The working power and the resultant physiological expression of the sensory acts are peculiar and idiocratic for similar degrees and amounts of external stimuli. Each apparatus holds its own grade of physical material and hence possesses its independent value of working force. This constitutes a true expression of the entire worth of the color apparatus. It is the sum total of its powers. It represents the greatest capability of the color-perceiving elements to be acted upon.

Totally different from this is the limitation of color perception that is dependent upon deficient functional activity as the result of want of education in color and lack of color training. Racial differences, sexual peculiarities, and constant association with color differentiation, all play their effective rôles in this type of defect. Many nations will possess finer color differentiation just as long as their inhabitants continue to employ the recognition of color as one of their most important means of existence. Women, who as a rule live among color changes more continuously than men, must perforce almost constantly exceed the male sex in their color powers;

while workers in color, no matter of what sex or nation, must necessarily acquire a much better color sense than those whose occupations do not require the determination of color differences. This can be well understood when it is considered that an educated musician is able to enjoy musical sounds that are ignored and in fact unheard by those who have less trained auditory apparatuses. In other words, education and training bring into recognized activity neuronic elements of color seeing and sound hearing that usually remain dormant and unemployed.

Color perception may be produced in several ways; that is, the neuronic elements may be excited into action by stimuli of various types and from different places. The visual sensory neurones, composed of physical elements that are adapted for the production of visible color, will, no matter in what way excited, give visual perception results. They are made for this purpose alone. In every such response there is a dual act: first, the employment of sufficient material to produce the visibility of the impinging color impulse or otherwise provoked stimulus; and second, the reformation of an adequate amount of substance to allow the immediate perception of a fresh impression.

Ordinarily, the impulse is received directly through the peripheral tips of the neurons in the macular regions of the ocular retina, giving what is known as direct vision. At the same time, a whole series of surrounding impulses are acting upon the circummacular regions of the same retinæ, producing indirect vision; the two composing what is clinically termed fields of vision and constituting the entire amount of physiological action of the commonly employed visual apparatus.

Symptomatic color expressions of inadequacy in this process, resulting from the response of remaining neuronic energies after perception of a primary impulse has taken place and before any fresh material in the sensory neurones has been obtained, are known as subjective aftercolor perception (so-called complementary colors, because the energy left is always equal to the subjective complement of the primarily seen color). These are many and most varied. For example, if a small red wafer be superimposed upon a sheet of white paper, and the eye made to gaze intently upon it for a few seconds' time, the underlying white areas will, when the wafer is suddenly removed, appear green in tint. Here the sensory neurones,

having been excited and employed so as to allow the perception of a red area in a white field, have suddenly exposed to them an area (previously occupied by the red) necessitating a greater degree of energy than that which was requisite for the perception of the red. The neurones used for this area, thus lowered in their powers by the red, give answer to their utmost ability, which, in this example, is merely sufficient to produce the perception of green.

Again, among what is known as simultaneous contrast colors, the answer is similar. Here the contiguous portions of the peripheral parts of the sensory neurones are unequally excited at the same moment, giving rise, as the conditions vary, to all manner of combinations of adjacent objective and subjective colorations. So, too, with the alternating subjective after-colors, or "multiple complements" as they are termed, in which alternating subjective perceptions of red and green, for instance, are set into activity. These are most probably dependent upon momentary regains and discharges of neuronic energies that are equal at the moment for the perception of the colors recognized.

If color perception be produced by an irritant other than color stimulus, no matter in what portion of the sensory neurones it may be situated, the result is known as subjective color. Blows upon the eyeball, irritation of the peripheral tips in the retina through inflammation in the contiguous tissues, vascular changes, neural disorder—all these, for example, serve as etiological factors in the production of this form of neuronic activity.

SUBNORMAL COLOR PERCEPTION.

As previously stated, every human visual organ is adequate for the perception of but few of the color differences that are resident in the spectrum of the sun or other illuminant; but although each color-perceiving apparatus has its limitations, yet, as can be well understood, there is an average perception below which, should any individual set of organs fall, it must be considered as having reached a subnormal stage and should be placed among the defective.

Forming but a part of so-called abnormal color vision (which is not infrequently abnormally increased in certain types and stages of organic disorder and disease), it expresses itself by a diminution of the color fields, a lessening of saturation or intensity of the colors themselves, and a loss of differential coloration.

Known and recognized for many years past, it at first offered itself as a mere literary curiosity. Later, better understood, it became a well-appreciated fact.

At present, all subnormal color perception is subdivided into two great groupings. The first is the congenital, consisting in a want of properly formed physical material: a true structural incapability as it were. The second is the acquired, in which either a properly made material or even a badly formed structure is lowered in its vitality by injury or disease occurring during its functional existence; a traumatic or pathological change taking place in the working lifetime of the color apparatus. The former is fixed and irremediable. The latter's betterment is always in direct relation with the nature, the seat, and the progress of the causative condition.

At the present time, the congenital form is found in about one out of every thirty males, and in about one in every thousand or more females. Heredity plays an important part in its production. Horner's law, based upon his remarkable series of ancestral cases, is quite frequently noticed.

Wilson and Jeffries have both noted a peculiar facial expression, principally ocular, in these cases.

The current naming of the various types of subnormal color perception depends upon whether the affected subject is designated by the coarse color differentiation he fails in or by those colors which he is able to recognize similarly with the average normally sighted. Wilson, Rose, Holmgren, and others obtain their systems of naming from the unrecognized color or colors, while Mauthner and Szokalski, for example, base their nomenclature divisions upon the colors which remain visible.

The naming of the condition in general has been just as varied. The many euphonious pure and mongrel coinages should all be discontinued, as they are, as a rule, both useless and inexpressive. Resource should be had to the comprehensive term "subnormal color perception," reserving the naming of the degree of the defect to a numerical value based upon the average relative ease of color differentiation, which could be easily obtained and would give an absolute answer to the grade of the defect, just as is done at present in expressing the valuation of direct vision for form.

In the congenital type, the preponderance of the number of cases begins with green and red. Blue and yellow blindness is excep-

tionally seen; while the so-called total variety—in which nothing remains but a photographic world, as in Magnus's well-known case of a school teacher who compared her color spectrum with a very finely executed lead-pencil shading growing darker from the natrium line (a very sharply defined yellow line in yellow) toward the unshortened end—in such delicate graduations that different gray wools were not sufficient to represent them—is excessively rare.

Should green and red be the two gross color differentiations that have disappeared, the position of the green in the solar spectrum will be, as a rule, occupied by a gray zone.

In the acquired form, green followed by red, blue, and yellow is the order of color loss that is usually found. If, in cases of gross inflammatory changes in the optic nerve and surrounding retina, a subsidence of the gross pathological changes takes place, there is frequently a temporary or a permanent regain of the colors—commencing with yellow, blue, red, and green; but the color sense is never brought back to the same degree as it originally existed. This, however, in the majority of cases, is sooner or later followed by a permanent though oftentimes extremely gradual second loss of color changes which take place in their original order of progression.

We are now brought to the question, What does a subject with subnormal color perception see? If we should ask a red-blind person to look at a piece of red worsted or a stick of red sealing wax, what will he tell us? He says he notices a peculiar difference in its shade which characterizes it from all other sensations, and his description of it will depend entirely upon the extent and position of his visible color spectrum. It must be remembered that he has no language for red as we see it; although he may learn by association to call a red object by its proper color name, yet he is unable to recognize that peculiarity which to a normal eye so strongly contrasts it with the other colors; the same being true of all the other forms of color blindness. Geissler says, for the red-blind the landscape has the character of autumn. A sunset or the beauty of our red flowers, with their various tones of blue and violet, he is perfectly indifferent to; but his fine sense for gray-white-blue shadows gives to glacial views a greater charm than to the normal eye.

Why should he be pitied? He has never known the color. It is to him what an unknown sense might be to us: we are contented, not knowing better, and he the same. Again, his bichromatic world,

for example, with its innumerable shades, may be a greater source of delight than our recognition of another color sensation.

There are many occupations open to the "color-blind," and even a few in which his infirmity serves as an actual advantage,—in photography and lithography, wood-cut, steel- and copper-plate engraving, and printing: in all of these, in which there is the want of an organ able accurately to differentiate between the many shades, he becomes an adept. Why could not an artist with subnormal color perception limit his productions to winter landscapes, lofty mountain scenery, studies in grays—thus obtaining wonderful and almost life-like facsimiles of nature? Why need he despair and complain when such a field of study and such a source of pleasure is thrown open to him—a character of work in which, by necessity, he must surpass all others who do not possess this now properly termed, to him, an advantage?

From this, however, it will be understood that not only is the recognition of the condition of importance to the individual, but it is quite frequently of value to the public at large. Placed in a position so as to misinterpret color signs, such subjects oftentimes become a menace to the safety of both human life and property.

For the practical recognition of the condition there have been many devices. These plans have been based upon three well-known methods: First, direct comparison of pigment colors; second, direct comparison of spectral colors; and third, the study of subjective after-color (complementary color).

The first, which is the most important and the one that is in common use for ordinary clinical purposes to-day, is best known by the wools of Holmgren that were borrowed from the papers of Seebeck and the worsteds of Wilson. Modified in all manner of ways by assortments of fixed colors that have been arbitrarily and even foolishly arranged upon cards, sticks, spools, cones, discs, and other articles, it has suffered the most varied of vicissitudes only to come back to the original plan of loose-wool selection that was strenuously sought for by both Wilson and Holmgren.

Maxwell's and Woinow's revolving discs, Hierlinger's and Magnus's tables; Lip's color triangles; the optotypi of Snellen; the color tables of von Reuss, Daae, and Roberts; the yarn-covered spools of Schenke; Kolbe's truncated cone, the pseudo-isochromatic wools of Donders, the embroidery patterns of Cohn, and the stick of

Thomson, constitute the majority of the devices that have been successively championed and upheld by their individual contrivers.

The more or less fixity of the tests, thus limiting the number of colors from which a choice might be taken; the arbitrary relationship of the component parts without any scientific reason, thus allowing them to fail to express the many percentages of lowered color-vision presented by the different candidates for examination, and permitting numbers of persons affected with subnormal color perception to escape by reason of the confusion, colors not being equal to the exact amount of the resident color error; as well as the liability of the methods to become known and understood, and thus rendered practically worthless when pursued among a great number of similarly placed individuals, are some of the main reasons why these latter plans cannot be satisfactorily employed.

Another plan by the same method is the placing of colored powders in homœopathic vials as pursued by Mauthner and Cohn. This has been done in order that the candidate shall not be able to differentiate color changes in yarns, worsteds, and wools by the supplemental use of the senses of touch and smell. That the objections these authors offer to the free handling of colored wools is in measure true there can be no doubt; a fact that as long ago as 1849 was pointed out by Wartman, who made mention of a man with well-marked subnormal color perception, who "corrected by the help of touch a part of the erroneous judgments which he formed regarding colors." This power of the possessor of subnormal color perception was reproven only six years later by Wilson, who justly attributed it to a delicacy of the tactile sense in discriminating between the harshness and the smoothness of variously colored dyes, and said "a wool dyed with a mineral green might thus be distinguished by the touch from one dyed with a vegetable, although the color-blind eye could detect no difference between their tints."

The second method (direct comparison of spectral color) unfortunately cannot be brought into every-day employment as an ordinary test for the quick detection of lowered color sense, although it can be made to serve a useful purpose in cases requiring more than ordinary observation, as among persons under judicial action. The apparatus is expensive; its mechanism is complicated and liable to become disarranged; both the examiner and the candidate must possess the necessary intelligence to handle the instrument; and the

dealing with spectral colors which are not the ones that the examiner is brought in daily touch with—these are some of the reasons why this plan must be relegated to the determination of a few selected cases.

The double spectroscope of Hirschberg, the polariscope of Rose, and the not very euphoniously named chromatophotoptometer of Chibret, are among the principal and most ingenious contrivances employed in the method.

The third method is practically useless. Much time and energy have been expended upon it. Contrivances of all kinds to show simultaneous and successive contrast colors have been devised. Prominent among them are the Heidelberg and Pflüger color books, Scina's mirror-contrast apparatus, Stilling's so-called chromatoskiameter, and Cohn's chromaskiopticon. Unfortunately, in this series of experiments, vague subjective colors are dealt with; uncertain color intensities and, in fact, absolute changes of color vibration are used; and the adjustments of the instrumental technique are frequently uncertain and misleading.

In addition, the examinate is required to compare the subjective color with some known series of colors such as wools and papers, which might as well have been done primarily by the ordinary method of loose-wool selection.

For general clinical purposes, some scientifically arranged collection of loose wools is by far the best, the cheapest, and the most easily handled material that can be used for testing the value of the color sense.

The series brought forward by myself are composed of a number of loose test and match skeins that have been carefully graded to equal relative intensities. Each color has its tint expressed in such a way that while its value is unintelligible to those who are being examined, an exact index of the character and the amount of color perception of the subject is given. The wools themselves have been made of one grade of manufacture and are dyed with vegetable materials. They can be employed by any educated layman (even though he himself have subnormal color perception), and with them records of all passing color changes may be kept for future comparison.

For the study of the color sense in railway and marine services resource must be had to another plan. This, which I have pointed

out, consists in placing the candidate in the actual position in which he is afterwards expected to discern properly the colors employed for signalling purposes. Miniature lanterns containing ungauged arbitrary color differences, such as those of Thomson and Williams, held fifteen or twenty feet away from the subject, are most uncertain. The candidate must be tested with adaptations of apparatus that are as nearly as possible like those which are used under ordinary circumstances—*i.e.,* when he is employed at his work. The testing must be done under the actual conditions which are supposed to exist while the candidate's color sense is protecting life and property.

As early as 1855, Wilson determined, as the result of numerous examples and experiments, that not only could color be recognized correctly at short distances and not distinguished at longer ones where such colors were plainly discernible to the normal-sighted, but he also found that the sensitiveness to the colors, while being gazed at, became more quickly lost as they were removed from the eye of the "color-blind" than when they were removed from the unimpaired visual organ. This, which he aptly termed "chromic myopia" or "short-sightedness to color," expresses in a word or two why candidates for positions necessitating color recognition at comparatively long distances, or what I have designed as "safety distances," cannot be considered as adequately determined when they have been tested by the ordinary methods of loose-wool selection or other near-at-hand tests.

Examination of such candidates at safe distances becomes a necessity. The determination of the color sense along the visual line, or what is generally known as foveal vision, is the main requisite, this being particularly so when it is considered that in the acquired types of color defects produced by the introduction of toxic agents, such as tobacco and alcohol, into the system, it is in the central area of the visual field that the color becomes diminished in saturation or is lost. The findings at one or even two metres' distance are in this character of cases worse than useless: they are dangerous. As just said, the degree and the amount of color sense must be known when the organs of vision are placed under the same circumstances as they would be when it becomes necessary that they should be the sole means for the avoidance of threatened accident or the prevention of imminent danger.

Laden engines, for example, moving with the rapidity of twenty to thirty-five metres each second, or so-called traction trolleys which run at such high rates of speed, would be propelled into destruction long before any engineer with "chromic myopia" could check their speed. The lesson for the recognition of the customarily used signal must be made at a distance which is sufficient for a proper control of the moving mass. It must be known that the candidate for such work is able to recognize color at long distances. To accomplish this purpose, the candidate must be made to select definite kinds and intensities of both reflected color by daylight and transmitted color by artificial light stimulus placed at distances that are requisite for safety in after-work.

The test that I have applied for this purpose among railway employees consists in a fixed apparatus which can be placed anywhere upon the company's property. Wooden frames containing properly and proportionately sized match and confusion colors of bunting for daylight work, or illuminated plates and lanterns of transmitted color for bad weather or night, are to be lined in a row in any order whatsoever, just as the wools are promiscuously thrown upon a table. The five test colors similar to the ones I have employed for the near tests are placed in an upper tier. Just as with the near-work tests the candidate employs one eye at a time. This done, he is then made successively to designate by the actual position of the color in the lower line the nearest numerical match to each of the upper test colors. This selection by number is to be handed to the examiner, who after having obtained the true color names of the numbers chosen for the occasion by the attendant, places the choosings upon suitable blanks for permanent registry.

To obtain the different percentages of light stimulus and to simulate as nearly as possible changes in character of weather (fog, rain, etc.), variously tinted glasses can be used, although preferably, the candidate can by this plan be tested during the actual states of weather.

An experimental track with a number of open switches so arranged that the sidings pass directly beneath certain colors would be useful for practically testing the color vision that is necessary to employ while running locomotives, trolley cars, etc., at full and even high rates of speed.

In marine service the danger is increased. All vessels carry a

green light on the starboard side, and a red light on the port, each being so boxed as to be seen forward and amidships. These are accompanied by a low white forelight, and sometimes by a high white aftlight. Hence, by comparison, a vessel's course can be easily distinguished. If, under such conditions, however, a heavy fog, or snow, or a rainstorm were to exist, it can be understood how an official with subnormal color perception, judging these important color distinctions by their intensities alone during the best of weather, is placed in a position that practically amounts to the absence of signals.

For the detection of the defect in marine and naval work, quite simple modifications and adaptations of color testing by which adequate data may be obtained can be made.

In all railway or marine testing, care must be taken that both the test and the later working colors should be graded in proportionate sizes and relative intensities of tone, thus giving similar distance values to every color used in the tests. That this should be done will be at once appreciated when it is remembered that different degrees of vividity of color areas of equal size produce such alterations in impressions that the colors give rise to false perceptions regarding their relative distances from one another.

Again, the dominant colors of the reflecting surface near which the test is made (as, for instance, the green of a hillside, the gray and white of a mountain top, and the blue of an ocean surface) all play important rôles as to the value of the tests.

The character of the illuminant itself is of the greatest importance. The blue of diffuse daylight, the greenish or nearly white tint of incandescent zirconia or metallic oxide mantles, the varying degrees of yellow rays from oils, illuminating gas and carbon loops, and the purples of free arcs of electricity, show how variable in tint color areas must become when exposed to these different agents.

Endeavors should be made to try to overcome the totally different values that are empirically placed upon the hues of the test colors themselves. This might be done by assuming pigment hues which are equivalent, with the midway bands in the corresponding portions of the solar spectrum. Such selections could be determined mathematically and analytically by an international commission, and reproduced in pigments from a consensus of examination by national or sectional sub-committees of competent observers possess-

ing normal color vision. These pigments could then be used for signal boards, signal lights, and test colors in any given locality.

There should not be any degree of standard in regard to the color capacity of any railway or marine official whose routine duty consists in the differentiation of color. Such positions are relatively so few when compared with the great supply of available candidates, and the responsibilities so grave, that no exception should be made. Such candidates should be rejected without a particle of sentiment.

The lack of systematic and periodic re-examination of the color sense is another great evil. This inefficiency in color testing is most reprehensible. After every case of severe injury or attack of illness that might be likely to produce visual disturbance, an examination should be made; moreover, among those who are known by strict, and yet silent, surveillance to use any toxic agents, such as tobacco and alcohol, the tests should be painstakingly and frequently tried.

The increased responsibility acquired by civil service, in which older subjects who are more prone to exhibit acquired color defects than younger ones, and who are at times given positions that usually necessitate the greater employment of normal color organs than before, should be especially subjected to careful periodic repetitions of some of the more important measures which are employed for the determination of the amount and degree of the color sense.

Losses of color in the so-called visual fields are quite common. They assume many forms, and quite frequently are expressive of definite types of both local and general disease.

Symptomatic in character, they oftentimes help demonstrate the exact position of intracranial disturbance, prove the actual functioning condition of inflamed and degenerating local tissues, give answer to situations of gross orbital change, and serve to distinguish functional complaint from organic disorder.

They are obtained in various ways: first, by ruled blackboards upon which small colored objects are carried towards central fixing points; second, by perimeters, which are mere mechanical contrivances for carrying small areas of color inward upon graduated metallic arcs toward fixed central points; and third, by similar movements of the outstretched fingers, lighted tapers, and focussing mirrors.

To be strictly accurate they should be repeated under varying conditions of time, luminosity, distance, and position.